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Hardy Lomax Shirley

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By Hardy L. Shirley

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ECONOMIC SIGNIFICANCE OF THE ASPEN

With the advent of commercial logging and land clearing in the Lake States, some 70 years ago, aspen and brush began a rapid invasion of the region's conifer lands; today these inferior forest types have spread to and are holding more than 18½ million acres of upland. The extensive aspen and scrub-forest lands in almost all parts of the region present an overwhelming economic and biologic problem to those who are dependent upon them, wholly or in part, for a livelihood. To those who look to tourists, hunters, or fishermen as their source of income, aspen may seem a fairly satisfactory type because it reclothes cut-over land and furnishes a favorable habitat for game; but tourists tire of unbroken stretches of monotonous scrub forest and are repelled by the poverty that results from meagerness of natural resources. To farmers and townspeople aspen is largely a weed tree, fit chiefly for poor-quality fuel and temporary fence posts. To county and State tax officers, aspen land represents only a financial drain, because it must be supplied with roads

[1] Received for publication June 15, 1940.

[2] The writer, now Director, Allegheny Forest Experiment Station, Philadelphia, Pa., wishes to acknowledge the aid of the many men who during 10 years spent in the Lake States were associated with him in this study. Special acknowledgment is due Joseph Kittredge, Jr., who initiated the project in 1926; Paul Zehngraff, who did most of the field work in 1933–39; and Clarence Knutson, who has tested the utility of heavy machinery in preparing aspen lands for conifers.

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and elementary governmental services even though it yields only a negligible revenue. To loggers, aspen has been a tree of last resort; here and there it develops good stands of timber that command a fair price, but generally it must be logged on a very narrow margin or with underpaid labor.

Persons remote from the problem have proposed that aspen be allowed to occupy upland forest areas in the Lake States until a market can be developed for the small-sized and often inferior timber it is capable of producing, or until the more valuable timber types are restored by natural processes. If a greatly expanded market for cellulose wood were in sight, or if natural restoration could be expected within a period of even three to six decades, such a proposal might be accepted by the public at large with assurance that the problem ultimately would be solved. On the contrary, those upon whom the burden of unproductive land bears most heavily advocate that an immediate effort be made to reinstate the more valuable timber types.

Aspen scrub forests and brush today occupy some 18½ million acres,[3] or 39 percent, of the Lake States' upland forest area. The aspen type includes quaking aspen (*Populus tremuloides*), bigtooth aspen (*P. grandidentata*), and balsam poplar (*P. balsamifera*). Associated with these is paper birch (*Betula papyrifera*), which almost always forms a substantial portion of the total stand. Roughly the region occupied contains 5 million acres of medium- to good-quality aspen that has replaced eastern white pine (*Pinus strobus*) and hardwoods; 5 million acres of poor- to medium-quality aspen that has replaced stands of the spruce-balsam type; 5 million acres of poor-quality aspen that has replaced red pine (*P. resinosa*) and jack pine (*P. banksiana*); and 3½ million acres of upland scrub forest and brush.

Of the former forest types displaced by aspen, the northern hardwood type occured on the upland clay and loam soils, attaining best development in the Upper Peninsula of Michigan and northern Wisconsin; there it consisted chiefly of sugar maple (*Acer saccharum*), yellow birch (*Betula lutea*), American basswood (*Tilia glabra*), American beech (*Fagus grandifolia*), and eastern hemlock (*Tsuga canadensis*), with white pine occurring as scattered individuals. In Minnesota beech and hemlock both were absent, and the size of the hardwoods progressively diminished as the prairie border was approached. Eastern white pine occurred in almost pure stands or in mixture with red pine on the sandy loam and sand soils of Michigan and Wisconsin. Such stands were dense and relatively free from an aggressive understory of brush. In Minnesota an understory of brush or small hardwoods was characteristic of white pine stands, with natural reproduction absent or of minor importance. Red pine and jack pine occurred on sandy soils throughout the three Lake States either in pure stands or in admixture with each other and with white pine. Upland scrub forests were of two main types:

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[3] Statistics on the extent of the original and present stands of aspen and other forest types in the Lake States have been computed from Forest Survey data. Most of the data used here are included in two mimeographed releases of the Lake States Forest Experiment Station: METHODS OF PREDICTING GROWTH OF FOREST STANDS, by S. R. Gevorkiantz and William A. Duerr, Economic Notes No. 9, 1938; and FOREST AREAS AND TIMBER VOLUMES IN THE LAKE STATES, by R. N. Cunningham and H. C. Moser, Economic Notes No. 10, 1938.

In the first, aspen and paper birch with various tall shrubs, such as American hazel and beaked hazed (*Corylus americana* and *C. rostrata*), willows (*Salix* spp.), hazel alder and speckled alder (*Alnus rugosa* and *A. incana*), and mountain maple (*Acer spicatum*); the second, mixed oaks (*Quercus* spp.[4]) and paper birch.

The aspen logs used for saw timber, box bolts, veneer core, and match and novelty stock are cut chiefly from former hardwood and white pine lands. In fact, it is only on these lands that aspen can be managed profitably for timber crops. Where a local market exists, pulpwood for wallboard, crating wood, and fuel may be harvested from the best part of the former spruce-balsam land now occupied by aspen. Merchantable aspen is confined almost exclusively to these 10 million acres. On one-third or more of this area aspen logging is not profitable because of poor quality or inaccessibility. On the 8½ million acres of land clothed with low-quality aspen, scrub forests, and brush the short, limby, rot-weakened tree stems may furnish residents with some low-grade fuel or posts, but bring no cash income. Altogether, including the more than 3 million acres of unproductive land formerly occupied by spruce-balsam and white pine forests, noncommercial aspen and brush lands in the Lake States amount to more than 10 million acres, an area greater than the combined land surfaces of Maryland and Delaware. Moreover, these areas are increasing; the land annually added to them as a result of injudicious methods of logging, uncontrolled fires, and the brush and aspen invasion of deforested land temporarily occupied by grass, bracken, sweetfern, and low brush, far exceeds that reverting naturally to conifers.

The economic blight which today characterizes much of the forested region of the Lake States is due in no small part to this replacement of pines and other valuable species by scrub forests and brush on 15 percent of the potentially productive upland forest land, and to the fact that an additional 18 percent of this land supports a timber type of low value. This idle and partially productive land represents an economic loss, in forest products, employment, and monetary income, just as real as the loss represented by idle factories and empty dwellings.

The economic results of this conversion are depicted in figure 1. The left half of the chart indicates what sort of forest cover the land would support and the products it would now yield annually if fire protection and simple forestry measures had been practiced; the right half indicates the actual forest cover at present, developed under conditions of uncontrolled fires and destructive logging, and the type of products marketable annually from this vast forest acreage. The approximate percent of merchantable aspen is indicated by the percent of standing trees.

Had the 10 million acres of nonproductive aspen and brushland stocked with the original forest types, it could be producing annually, at a fairly conservative estimate, 550 million board feet of timber, whereas its actual production is only 75 million board feet. The difference of 475 million board feet represents a stumpage value of approximately $1.500,000. Logging this timber and manufactur-

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[4] Northern red oak (*Quercus borealis*), northern pin oak (*Q. ellipsoidalis*), scarlet oak (*Q. coccinea*), white oak (*Q. alba*), and bur oak (*Q. macrocarpa*).

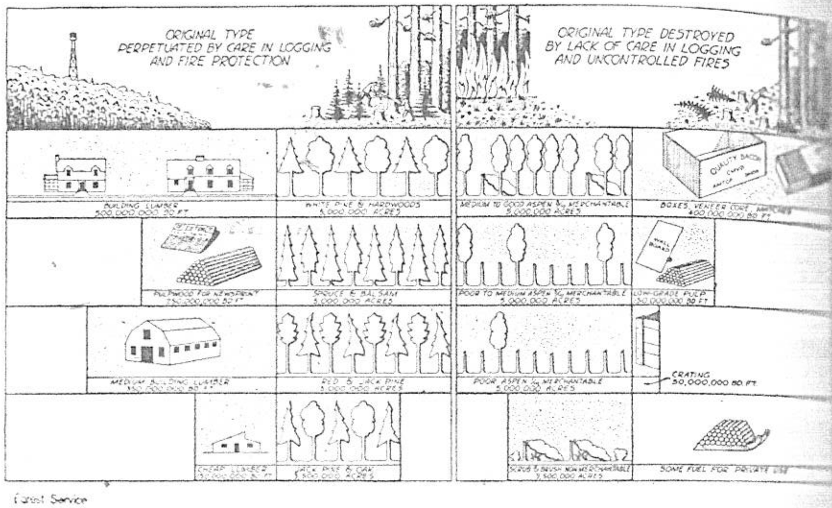


FIGURE 1.—Present annual timber-productive capacity of 18½ million acres of aspen and brush lands contrasted with yields these lands could be producing had the original type been perpetuated. Area and quantity of product are represented by length of bar. Fallen trees represent timber that is rotting as the stump, either prematurely or because of not being logged at maturity.

ing the logs into lumber or other primary products by present methods would provide employment for at least 5,000 laborers and create values approximating $7,500,000. These figures, weighted for species and areas, are based on actual yields of medium-quality unmanaged stands and actual stumpage prices current in the Lake States in the years 1928–37 (*14*).[5]

The differential in annual timber yield for the other 8½ million acres of former white pine, hardwood, and spruce-balsam land is 175 million board feet; this loss in yield and the loss in monetary return due to the low stumpage value of aspen and of the primary products manufactured from aspen, make up an annual loss approximating $8,300,000.

These annual losses, aggregating some $16,000,000, present a stirring challenge to foresters, to the timber industry, and to those who are responsible for forest land policies in Minnesota, Wisconsin, and Michigan.

In this bulletin no attempt is made to discuss the probable future uses and markets for aspen, or the possibilities or methods of managing aspen as a timber crop on those lands best suited to its development. Detailed treatments of these subjects by Johnson, Kittredge, and Schmitz (*5*) and by Kittredge and Gevorkiantz (*7*) clearly indicate that much is now being done and that much more can be done in the future to exploit the aspen resource. A candid estimate of the situation indicates, however, little probability that such exploitation will result in either full utilization of aspen or a decent standard of living for those engaged in the work. It is therefore prudent to consider the possibilities of restoring conifers or other more valuable types on at least part of this land.

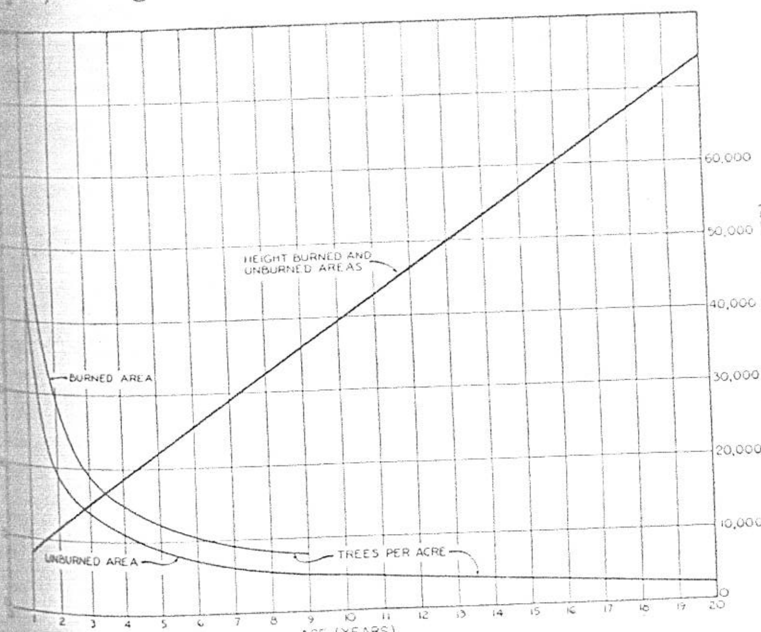
[5] Italic numbers in parentheses refer to Literature Cited, p. 36.

purpose of this bulletin is to direct attention to the forces ...ve caused the rapid spread of aspen on the upland forest ...f the Lake States, as well as to those that impede the return ...ful conifers. The above estimates of the economic loss in... in land idleness, of the costs of restoring conifers, and of the ...le returns from such an effort have been introduced to provide ... for weighing the probable benefits from a restoration program ... the benefits likely to be derived from other conservation ...s of equal cost. To make the problem understandable in all ...pects, the life history of aspen stands is described, and the ...ility that aspen may be forced into a hasty retreat by its ...l enemies is considered. Finally, an effective method is de... for ejecting aspen and replacing it with conifers. In view ... economic importance of the problem, and the difficulty and ...ss of the method of artificial replacement, a policy for public ... is set forth.

THE ASPEN CYCLE

Logging and Fire Perpetuate Aspen

...en is one of the first woody plants to invade cut-over and ...d forest lands in the Lake States. The seeds are tiny—2 million ... only 1 pound. Buoyed by long silky hairs, they are carried ... by air currents, and in spring form a cottony blanket over land ... Delicate and short-lived (*9*), only those that fall on moist, ...pied soil will produce seedlings. Freedom from competing ...ation is essential throughout the seedlings' first year. Within ... year, seedlings attain heights of 12 inches or more and develop



...RE 2.—Number and height of aspen sprouts arising after logging on burned and unburned areas.

strong taproots 8 to 10 inches long. During the second and third years they form wide-spreading lateral roots, often two or three times the length of the stem. From the second year on, root sprouts spring up abundantly if the stems are killed by fire. Sprouts appear to come in more densely on lands logged and burned than on lands logged but not burned (*10*) (fig. 2). Repeated burning at frequent intervals tends actually to thicken aspen stands, because it prepares the soil for new seedlings and stimulates root sprouts; unlike any other tree species in the region, aspen can spread and hold the land it has invaded even though subjected to fires at intervals as short as 3 years. Such frequent fires soon eliminate all conifers, including jack pine. Of all the local tree species only paper birch, a common constituent of aspen stands, approaches aspen in the capacity to colonize burns.

Though aspen spreads most rapidly after fires on cut-over land, or fires in swamp forest that completely destroy the original type, it may successfully invade pine or other forests after fires that only thin the stand. It is not uncommon to find aspen and paper birch dominant in the understory of a mature pine forest, especially in Minnesota, where remnants of virgin pine still exist (fig. 3).

Good-quality aspen may be harvested at an age of 35 to 40 years for pulpwood, and at 50 to 70 years for saw timber. In any case sprouts arise after each heavy cutting, and thus cutting perpetuates the aspen stand. If harvesting at either age results in clear-cutting, which is seldom justified financially, the crop of sprouts will be abundant. If partial cutting is practiced, especially in stands aged 50 years or younger, many of the trees left will later on become mer-

FIGURE 3.—Aspen 29 years of age, which, after fire, invaded an uneven-aged mixed red and white pine stand.

chantable. It may be expected that all accessible high-quality aspen forests will henceforth be logged at maturity, and that in consequence they will be perpetuated indefinitely. Fires that kill aspen trees of any age, of course, also regenerate the stands and perpetuate the type.

Even if not logged at maturity and not burned, aspen appears to be perfectly capable of reproducing. When the rot-weakened stems of veterans break off, root sprouts come up in sufficient quantity to form a new stand.

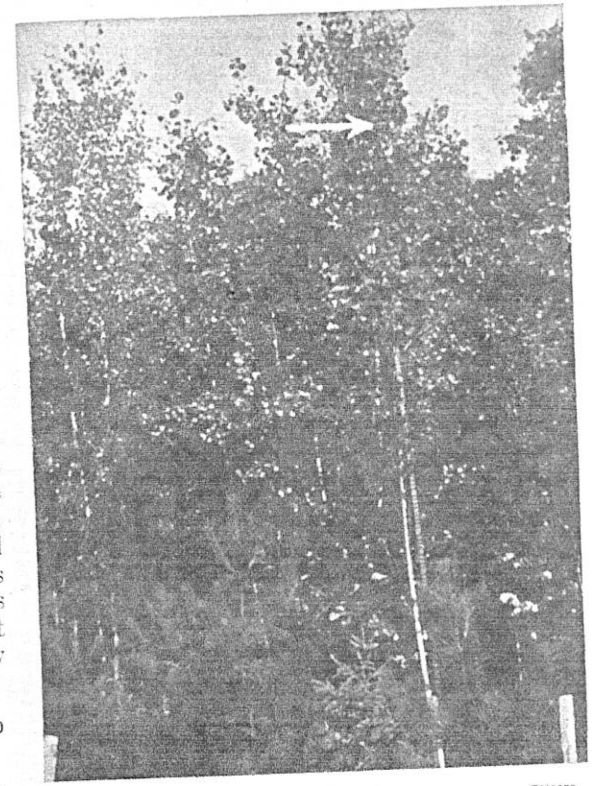


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FIGURE 4.—Aspen sprouts 7 years old, which arose after clear-cutting. Arrow marks top of 16-foot measuring pole. Pines and spruce in foreground, 2 years older than the aspen, were planted immediately after logging and kept free from competing vegetation by periodic weeding.

ASPEN MATURES AND DECAYS EARLY

No available evidence indicates that stands of sprout origin are any less vigorous than those of seedling origin. Certainly they equal them in vigor at the age of 50 years. Rapid growth and high mortality are characteristic of young aspen forests, whether of seedling or sprout origin. Seedling stands attain heights of 6 to 8 feet in 5 years, 25 feet in 13 years, and 37 feet in 20 years. The growth of sprouts is greater than that of seedings the first 2 to 4 years, but is about equal to it thereafter.

Natural thinning is rapid. Seedlings below the general crown level stop growing and die within a year or two. Mutual crowding restricts diameter growth and crown development, but young aspen stands show little tendency to stagnate. Dominance is pronounced (fig. 4). At the age of 20 years the number of stems per acre has been reduced to about 2,500; at 29 years to about 1,000. Subsequent changes in density are shown in yield tables (*7*).[6] Aspen forests reach their peak (fig. 5, *A*) at about 40 to 60 years of age; thereafter they open up, as wind throw and ice breakage eliminate individual trees and decay takes a heavy toll of both large trees and small.

[6] See also footnote 3.

Stands on poor soil may become decadent at 40 years or earlier, th on best soils may maintain a good crown canopy until 60 years of At 80 years only a few decadent veterans remain (fig. 5, *B*). Th marks the end of the first aspen cycle.

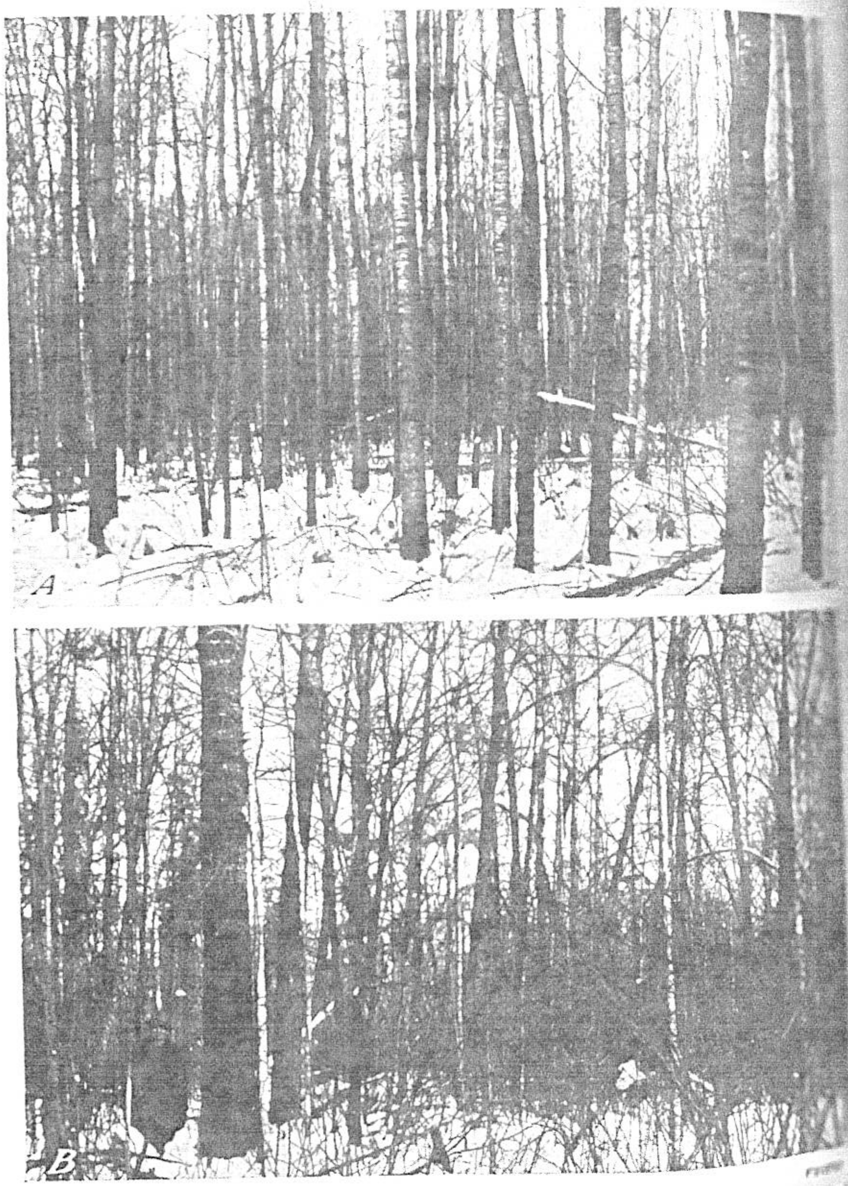

FIGURE 5.—Mature and overmature aspen stands: *A*, In this high-quality stand 45 years old, dominant trees average 70 feet and 7.5 inches d. b. h., and an understory of tall shrubs and herbs is already well-developed. *B*, The end of the aspen cycle; sprouts from wind-thrown veterans have already gained dominance over the dense understory of tall shrubs in this 80-year stand.

NATURAL ENEMIES OF ASPEN

fungus *Hypoxylon pruinatum* (Klotzsch) Cke.,[7] causes stem which take a heavy toll in aspen stands 10 years of age and The cankers appear near the base of the crown and either the stem or weaken it so that it breaks off. Within a year or fter they appear, they may kill trees of any size. *Fomes igni-* (L.) Fr., which causes heart rot, infects stands 30 to 80 years and is responsible for most of the cull. Johnson, Kittredge, hmitz (*5, p. 21*) have estimated that cull due to heart rot 20 percent in aspen stands 70 years of age. Anderson,[8] in nsive study of aspen stands in Minnesota and Michigan, found percent of cull increased with tree diameter, and also that rer the soil the greater was this percentage. Of trees 12 inches re in diameter, on pine land 29 percent were culls; on spruce- land, 20 percent; and on hardwood land, 16 percent. Also, chantable trees of this size 19 percent of the gross volume was to be cull. Other diseases attack aspen twigs and leaves but appreciable effect on stand development or regeneration.

nd only to the fungi causing canker and heart rot is the forest terpillar (*Malacosoma disstria* Hbn). During the period its larvae defoliated aspen over large areas in Minnesota. three successive defoliations, many trees died. This insect tive both in the aspen-birch type and in aspen growing in e with northern hardwoods. When followed by the variable f caterpillar (*Heterocampo manteo* Doubleday) that defoli- birches, oaks, basswood, and elm, together with many of h shrubs, damage to existing vegetation was extreme. Areas ch both overstory and understory were defoliated to the extent percent or more were, however, few and small in size.

en, particularly when growing on poor sites, is subject to by a number of other diseases and insects that, though they t be directly the cause of death, weaken the tree and prepare y for other destructive agents. Among these the poplar (*Saperda calcarata* Say) is particularly active in parts of rn Wisconsin. One aspen dissected in Minnesota revealed a series of pests with evidence of succession as the tissue was ned, killed, and decayed. The upper stem and most of the was killed by stem canker. Through a fire scar at the base rot had entered, followed by carpenter ants. Just above the was the poplar borer and above these in uninfected wood a borer, probably the poplar curculio.

USH AND SCRUB FOREST STANDS IN RELATION TO ASPEN

minant stands of tall woody shrubs in the Lake States have in common with aspen forests. These definite brush types are d on sandy soils by American and beaked hazel, speckled and

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[7] , ROLLAND C. and CHRISTENSEN, CLYDE M. A SURVEY OF FOREST TREE DISEASES E RELATION TO STAND IMPROVEMENT IN THE LAKE AND CENTRAL STATES. October [Mimeographed.]

[8] SON, ROBERT T. YIELDS OF ASPEN IN THE LAKE STATES. U. S. Forest Serv. States Forest Expt. Sta., Forest Res. Digest, May–June 1936, pp. 3–7. [Mimeo- d.]

hazel alder, roundleaf serviceberry (*Amelanchier sanguinea*), prai[rie] and Bebb willow (*Salix humilis* and *S. bebbiana*), and comm[on] chokecherry (*Prunus virginiana*); and on loamy soils by pagoda, roundleaf, and red-osier dogwoods (*Cornus alternifolia, C. rugosa,* and *C. sanguinea*), mountain maple (*Acer spicatum*), nannyberry and American cranberrybush (*Viburnum lentago* and *V. trilobum,* syn. *V. opulus americanum*). Tall shrubs are present as an understory in pine, aspen, hardwood, and spruce-balsam forests, and become dominant when the timber has been logged or killed by fire. They sprout from roots, root collar, or stem, reach maturity at about 20 years of age, and degenerate and rejuvenate in a manner not unlike that of aspen. They vary in density from scattered clumps to almost impenetrable thickets (fig. 6). Tall shrubs are

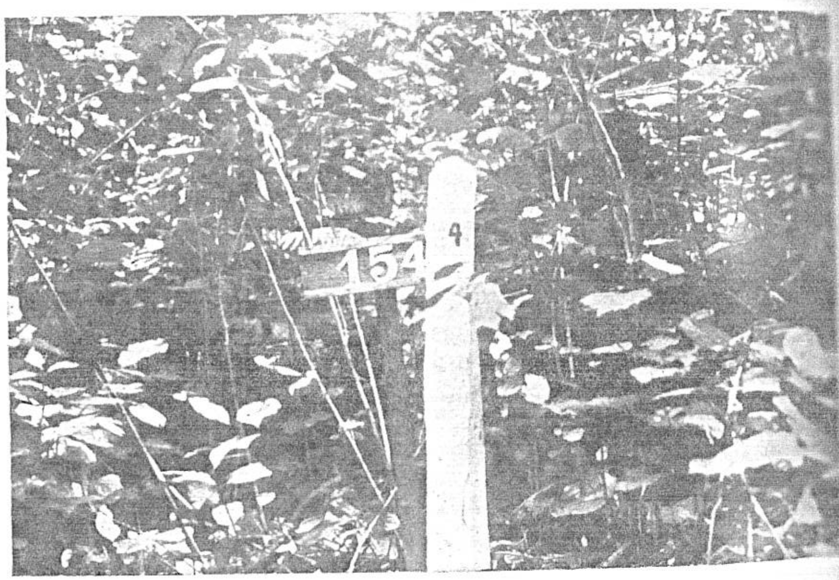


FIGURE 6.—Thicket of tall shrubs that for 8 years have effectively suppressed planted conifers.

rarely found in pure stands over large areas. More commonly they occur in mixture with scrub forest species, which extend their dominance after each fire and during each stage of decadence.

Scrub forests in the Lake States, likewise, are similar to forests of aspen, being made up chiefly of aspen, paper birch, and oak. Their poor growth rate results from poor stocking, poor soil conditions, or both. Scrub forests of aspen usually have a dense understory of shrubs; ecologically they represent a transition type between brushlands and aspen forest. Oak scrub occupies the driest soils, and may or may not have an understory of tall shrubs, but it presents obstacles to young conifers that differ from those in scrub aspen forest more in degree than in kind.

[OB]STACLES TO NATURAL RESTORATION OF CONIFERS

[Ec]ologists and foresters consider aspen in the Lake States a transi[tional] forest type. There is much evidence to support this view. Be[fore] the advent of commercial logging, aspen was confined chiefly [to sh]ores of receding lakes or streams and areas recently swept by [fire, wh]ere it occupied altogether only about 1,700,000 acres. More[over], an understory of balsam fir (*Abies balsamea*) and species of [pine], spruce, and hardwoods is not uncommonly found in aspen [stand]s. These species, being longer lived, are presumed to be des[tined] ultimately to displace aspen, provided the forest is not dis[turbe]d by logging and fire. No competent observers oppose this [view]. The questions of most immediate concern regarding conver[sion] of aspen forests to forests of more valuable species are, how [soon] will conversion take place on undisturbed areas and will log[ging] hasten or delay the process?

[As] a factor possibly impeding the restoration of conifers, climate [may] be quickly dismissed. No evidence exists to indicate that the [clima]te of the Lake States has become unfavorable to conifers. The [fact] that conifers still grow throughout the territory they originally [occu]pied is proof to the contrary. During the years 1930–36, when [drou]ghts were frequent and severe, heavy losses occurred in conifer [plan]tations on open sandy areas, but plantations of the same species [on as]pen lands sustained only moderate losses. Furthermore, there [was] not a single year in which pine seed sown in aspen forests failed [to ge]rminate well, though that sown on open sandy areas germi[nate]d poorly in all except the most favorable years.

[The so]il in aspen forests, also, gives no evidence of being unfavorable [to] conifers; on the contrary, it has been found highly favorable. [Whe]re conifers are mixed with aspen but not suppressed by it, they [grow] rapidly. It is conceivable that heavy soils might be unfavor[able] for conifers immediately after hot fires in logging slash, but if [area]s of such soils are invaded by aspen the topsoil soon regains a [stru]cture favorable for conifers and other tree species.

INADEQUATE SEED SUPPLY

Throughout the aspen and brush lands, conifers of seed-producing [si]ze are scarce, averaging only about 1 to 3 per acre. This is an [ine]vitable result of unrestricted logging, which still continues. Un[for]tunately, reliable data are not available as to the proportion of [cu]t-over land in the Lake States adequately stocked with seed-bear[in]g trees, but Forest Survey parties report that it is small. Seed [tree]s, to be effective, must be both plentiful and well distributed. [St]udies in Michigan by Paul Rudolf have shown that most jack [pi]ne seed reaches the ground within a distance from the base of the [tree] not greater than half the tree's height. Jack pine seedlings in [Mi]chigan are reported by Watson [9] to be abundant only within 15 [fe]et of the parent trees. The area adequately supplied with seed [fro]m red pine in Minnesota averaging 90 feet in height did not [ex]tend beyond 100 feet of the border of the stand.

[9] Watson, Russell. JACK PINE TREES IN MICHIGAN. U. S. Forest Serv., Nat. Forest [Regi]on 9. 1937. [Mimeographed.]

Seed production of Lake States conifers is characteristically irregular. Jack pine, one of the most regular cone bearers, has been found to disperse annually only about 3,000 to 11,000 seed per acre (*3*). It produces far greater quantities, but most of the seed remains on the tree in unopened cones to be released only after logging or fires, at which time, in well-stocked stands, as many as 1½ million seed per acre may be dispersed. The other species release their seed more promptly but bear irregularly—white pine and white spruce (*Picea glauca*) at 2- to 3-year intervals and red pine at 3- to 8-year intervals.

In some localities birds and rodents often consume as much as 90 percent of the normal annual seed crop. By comparing the number of new seedlings on control areas supplied by seed trees only with the number on areas supplied with a known quantity of additional seed, it was estimated that only 3 seeds out of 100 of the abundant red pine seed crop of 1930 produced seedlings surviving the first growing season, even on plots where the soil had been rendered favorable for seedling establishment by disking (*11*). On 9 other plots artificially seeded in both spring and fall of the years 1930, 1931, and 1932, and protected by wire screens from birds and rodents, 50 percent of the 720 seed spots contained seedlings at the end of the first summer, whereas only 19 percent of 4,520 spots not thus protected contained seedlings.

Inadequacy of seed supply is further evident in the distribution of seedlings in the neighborhood of red and white pine seed trees left after logging on the Chippewa National Forest, Minn. Seedlings were rarely found in abundance at distances from the seed trees greater than the trees' height. It must therefore be concluded that, irrespective of other conditions, inadequacy of seed supply is destined to prevent natural return of conifers to aspen lands for many decades to come.

Unfavorable Seedbeds

In the natural state, pine seed falls onto a bed of sod or litter, and shortly is covered by a heavy layer of fallen needles. Compacted by rains and snow, this material forms a mulch that enables some seeds to germinate in the duff; only the more hardy or more favorably located seedlings, however, can thrust their rootlets through the litter beneath them into the moist soil. The possibility that failure of pine seedlings to spring up abundantly in the neighborhood of good seed trees was due partly to the seeds' falling on unfavorable seedbeds led to experimentation to discover the adequacy of natural versus artificially prepared beds for germination and first-year survival. Red, white, and jack pine seed were sown in beds prepared in the fall of 1931 and spring of 1932 by these seven different methods:

1. Sod or litter removed; seed sown in narrow slit.
2. Sod or litter removed and used to shade spot on south side; seed pressed into soil.
3. Sod or litter removed; seed sown in broad depressions but not covered.
4. Seed sown in 1- by 6-inch slots, 2 inches deep, made by removing chunks of sod or litter.
5. Sod or litter finely chopped, by cross gridding with spade cuts 1 inch apart. Seed pressed down with the foot.

6. Seed sown in slits in sod or litter made by a single spade cut.
7. Seed sown on undisturbed sod or litter and pressed into the soil.

Four plots were used, 2 in the open and 2 in a jack pine stand, and 10 replicate spots were sown on each plot for each method, species, and season. Altogether 240 spots were thus prepared by each of the 7 methods. Counts were made in late spring to determine germination, and in the fall to determine first-year survival. The averages by seedbed treatment, and the least significant differences as determined by the analysis-of-variance method (*4*), are given in table 1.

TABLE 1.—*Effect of seedbed preparation method on germination and first-year survival of red, white, and jack pine*

Method	Spots in which seed germinated	Spots in which seedlings survived the first year [1]	Method	Spots in which seed germinated	Spots in which seedlings survived the first year [1]
	Percent	*Percent*		*Percent*	*Percent*
Sod or litter removed:			Sod or litter not removed:		
Seed sown in narrow slit	52	22	Seed sown in 1- by 6-inch slots	45	16
Spot shaded, seed pressed into soil	51	37	Sod finely chopped with spade, seed pressed into soil	38	26
Seed sown in broad depression, not covered	46	26	Seed sown in slits in sod	31	10
			Seed pressed into undisturbed soil	17	6

[1] Odds are 100 to 1 that differences of 11 percent in germinations and of 10 percent in survival are not due to chance. The data were treated by analysis of variance.

All three species germinated best in mineral soil, and least well in undisturbed soil.[10] Further tests with direct seeding (*12*) have indicated a definite need for a mineral-soil seedbed. Mineral-soil seedbeds are, however, uncommon in natural forests of the aspen type. Disturbance of the soil through the uprooting of trees by wind is rare, since aspen trees first break off and paper birch, having a strong, deep root system and a flexible stem, are little affected by windstorms. Exposure of mineral soil in aspen forests is almost wholly the work of animals, particularly pocket gophers, woodchucks, badgers, deer, and bears. Of these, only bears dig up the sod and surface soil in such a manner as to make a good seedbed, and they are so few that their effect is negligible. It must be concluded that in aspen stands of the Lake States the probability that pine seed will fall on a bed favorable for germination and growth is slight, reducing the seeding possibilities of the few surviving pine seed trees to hopeless inadequacy.

Excessive Plant Competition

Repeated failure of planted conifers to survive and make satisfactory growth in aspen forests, and failure of pine seedlings seeded naturally to gain ascendancy over the undervegetation and ultimately over the aspen itself, have convinced the most skeptical that adequate seed supply alone does not ensure restoration of conifers on aspen land within a reasonable length of time. Of the other factors in-

[10] Survival was best where the seedlings were lightly shaded.

volved, the most obvious is plant competition. This consists in competition of shoots for light and crown space, and competition of roots for soil moisture and nutrients. All the plants growing in the aspen forests are involved—the trees, the shrubs, and the herbs.

Shrubs and herbs offer particularly vigorous competition in decadent aspen stands with thin crown canopies. The most common and important species [11] are mountain maple, speckled alder, wild sarsaparilla (*Aralia nudicaulis*), bigleaf aster (*Aster macrophyllus*), bunchberry (*Cornus canadensis*), beaked hazel, poverty oatgrass (*Danthonia spicata*), dwarf bush-honeysuckle (*Diervilla trifida*), Virginia strawberry (*Fragaria virginiana*), and bracken (*Pteridium aquilinum*).

To what extent the undergrowth may reduce light intensity is illustrated by determinations made in 31 different aspen plots in Minnesota. On these plots the undergrowth reduced by more than half the light penetrating the aspen canopy. Above the undergrowth the intensity varied from 11 to 40 percent, with a median of 21 percent; beneath the undergrowth it varied from 4 to 27 percent, with a median of 9 percent.

To determine the light requirements of red pine, white pine, jack pine, and white spruce, 500 seedlings of each were transplanted into specially shaded beds in the forest nursery at Cass Lake, Minn., in the spring of 1931 and their survival and growth followed during a period of 4 years (*13*). Three beds, shaded with cloths, received 11-, 20-, and 46-percent light, and a fourth was covered with laths so spaced as to permit 43-percent light. An uncovered bed receiving 98-percent light completed the series. Mortality under 43-, 46-, and 98-percent light varied from 1 to 3 percent; under 20-percent light it was 12 percent, and under 11-percent light 27 percent. Total dry weight at the end of 4 years averaged 95 to 110 grams for the plants exposed to 43-, 46-, and 98-percent light, 40 grams for those exposed to 20-percent light, and 17 grams for those exposed to 11-percent light. In all beds jack pine grew most rapidly, white pine least rapidly.

It is concluded that the four conifiers need at least 20-percent light for high survival and approximately 40-percent light for optimum growth. It may be tentatively concluded, therefore, that in aspen stands, on the average, the light intensity beneath the undergrowth is unfavorable for survival and even that above the undergrowth is inadequate for maximum growth.

To test this conclusion, and to introduce other factors of competition, a study was made of the growth of young conifers planted on three ¼-acre plots in a 43-year-old aspen stand (*13*). On the first plot all trees were removed, on the second the basal area of 33.6 square feet was reduced by 36 percent, and on the third all trees were left standing. The basal areas left on the partially cut and uncut plots were 21.5 and 30.4 square feet respectively. On each plot 17 quadrats, 10 feet on a side, were laid out in such a way that they included no live tree or recently cut stump. Four quadrats were trenched to eliminate root competition and kept free from shrubs and herbs by frequent weeding; 4 were weeded but not trenched; 4 were subjected to a light fire, which consumed the litter and killed woody vegetation; and 4 were left undisturbed. These 16 quadrats, designated as trenched, untrenched, burned, and control, respectively, were enclosed within

[11] Statement based on frequencies reported by Kittredge (6) and studies of the writer on 36 plots in Minnesota and 10 in Wisconsin.

[illegible]itproof fence; the remaining control quadrat was given no [illegible]ent and was not enclosed. On each quadrat 25 red pine, 25 [illegible] pine, and 50 white spruce seedlings 2 years of age were planted.

Plant competition significantly modified two physical factors, light [illegible]sity and soil moisture. Light intensity was inversely related to [illegible] density of the upper canopy and understory. Soil moisture, [illegible]mined at weekly intervals, was critically low—within 1 percent [illegible] wilting coefficient—once on the trenched, nine times on the un[illegible]hed, and nine times on the control quadrats of uncut and par[illegible] cut plots. The other physical factors, air and soil tempera[illegible], atmospheric humidity, and evaporation. were only slightly af[illegible] by plot and quadrat treatment.

Survival of pine at the end of the fourth season, particularly of [illegible] pine, was low under 13-percent light, and fair to good under [illegible]ercent or more intense light (table 2). White spruce survived [illegible] irrespective of light intensity. Elimination of root competition [illegible] trenching resulted in no important advantage in survival, even [illegible] it did improve the moisture content of the soil during [illegible]ghts. Weeding was generally beneficial, in part because it [illegible]eased light intensity and in part because it lessened root [illegible]petition.

Growth in height and weight, on the other hand, was profoundly [illegible]nced by both light intensity and root competition (table 2). [illegible]her weeding alone nor weeding and trenching induced satis[illegible]ory growth where the light intensity remained at 21 percent. [illegible]-percent light, trenching and weeding resulted in much better [illegible]th, but this was still far below that attained where all compe[illegible] was removed. In contrast with the rapid-growing seedlings [illegible] weeded quadrats, seedlings overtopped by undergrowth grew very [illegible]. At the end of 5 years their dry weight averaged only 3 grams,

[illegible] 2.—*Survival and dry weight of red pine, white pine, and white spruce seedlings at end of fourth season, as influenced by light intensity and root competition*

[illegible] and quadrat treatment	Light intensity	Survival [1]			Dry weight [2]		
		Red pine	White pine	White spruce	Red pine	White pine	White spruce
[illegible] cut:							
Weeded:							
Trenched	*Percent* 100	*Percent* 82	*Percent* 75	*Percent* 88	*Grams* 289	*Grams* 89	*Grams* 141
Untrenched	100	78	73	70	339	35	85
Not weeded:							
Burned	13	9	33	85	1	2	4
Control	13	15	34	90	2	1	5
[illegible]ent cut:							
Weeded:							
Trenched	36	99	95	97	99	36	26
Untrenched	36	93	89	96	65	20	23
Not weeded:							
Burned	23	73	75	91	3	2	3
Control	23	68	87	88	3	2	3
[illegible]:							
Weeded:							
Trenched	21	96	92	97	36	27	25
Untrenched	21	100	93	99	12	12	8
Not weeded:							
Burned	13	25	70	85	2	2	2
Control	13	35	77	84	2	2	3

[1] [illegible]s are total survivals. Limitation of data preclude a statistical check.
[2] [illegible] 2 exceptions, standard errors are less than 17 percent of their corresponding means.

scarcely one-fiftieth of that attained by plants under best conditions. Plants in 23-percent light competing with undergrowth were only about one-fourth the size of those in 21-percent light free from undergrowth. Thus competition of undergrowth emerges as the primary factor inhibiting the growth of conifers in aspen forests.

Growth of conifers is similarly influenced on brush fields, whether aspen is present or absent. Conifers were seeded and planted in 1930 on three plots covered with a dense growth of willow, alder, hazel, and other shrubs such as that shown in figure 6. On one plot scattered oak sprouts grew up after a fire in 1930, and each of the other two plots was about half occupied by 13-year-old aspen and birch. Direct seeding was unsuccessful on all three plots in three successive trials. At the end of six growing seasons, survival of planted white pine and white spruce was low and their growth negligible (table 3).

Feeding by Deer and Hare

Deer, rabbits, and snowshoe hare are destructive of seedling conifers in aspen forests, especially where conifers are the only plants that remain green during winter. Damage may occur at any time during the dormant period and is especially severe in spring and fall, when the entire seedling may be consumed or nipped off. Because of repeated injuries, by 1938 the seedlings outside the fences on the three variously cut aspen plots described on page 14 had attained only half the height and had undergone twice the mortality of those on comparable quadrats inside. Conifers planted on other plots in aspen and on brush-covered areas have been heavily browsed by deer and repeatedly pruned back by hares. Similar losses have occurred in many other plantations. Although the animals are unlikely to destroy thrifty, rapid-growing conifers completely, they frequently finish off those already weakened through suppression by shrubs and herbs.

TABLE 3.—*Survival and height, after six growing seasons, of white pine and white spruce seedlings planted on brush-covered areas*

Type of overstory	Survival		Height	
	White pine	White spruce	White pine	White spruce
	Percent	*Percent*	*Feet*	*Feet*
Aspen-birch	5	16	0.2	0.4
Aspen-birch	14	53	.4	.7
Oak	44	61	.8	[illegible]

Cox (*1*) defends the snowshoe hare as useful in thinning young forest stands, and to support his contention presents 1-year data from 4 plots in jack pine. One plot was thinned from 55,000 stems per acre to 1,650, another from 3,180 to 10. To many foresters it will seem that the hare does his job of stand thinning too thoroughly. Is it not likely that the stand thinned from 55,000 to 1,650 stems per acre was thinned in the following year to 10 stems, and that the stand thinned from 3,180 to 10 stems originally contained more than 55,000? At any rate the data cited support the writer's own observations that

the thinner the stand the greater is the percentage of trees taken by ...s, provided aspen or brush is present to afford the animals cover. ...quently it appears that the activities of hares tend to delay ...finitely the restoration of conifers on aspen lands.

Aspen as a Nurse Crop

The concept that aspen, although of little value for anything else, ...s an excellent nurse crop to shelter seedling conifers during their ...y life has become part of forestry's dogma. To the noncritical ...rver and to those who hold the theory that all living forms have ...finite useful purpose to fulfill, this concept seems plausible. The ...ence of seedling conifers in aspen stands of all ages and of sapling- ...d pole-sized conifers in old aspen stands has led the unwary to con... ...e that aspen prepares the way for conifers, and that the latter ...low promptly at the end of the first aspen generation.

The material already presented affords convincing proof that dense ...e-sized aspen does not form a nurse crop for planted conifers in the ...es States, but has a deleterious influence on them. Earlier studies ...icated that it is equally deleterious to natural seedlings. On four ...ts laid out in 1927 in a 39-year-old aspen stand containing white ...e seed trees and a fair stocking of pine seedlings, the aspen was ...ted as follows: Clear-cut, 50-percent cut, 30-percent cut, and not ... Ten years after cutting, pine seedlings were less numerous than ...the beginning and, except where clear-cutting and brush cutting ...d been practiced, still averaged only about 1 foot in height (table ...). Aspen did not act as a nurse crop to favor establishment or ...wth of pine seedlings; instead, it smothered and suppressed them.

...E 4.—*Stocking and height of natural pine reproduction on variously treated plots in a 39-year-old stand of aspen*

Plot treatment	Basal area per acre after cutting	Pine seedlings per acre			Average height	
		1927	1931	1936	1930	1936 [1]
	Sq. ft.	*Number*	*Number*	*Number*	*Feet*	*Feet*
...al	87.2	200	200	40	0.50	0.80
...percent cut [2]	82.9	1,320	1,200	900	.44	1.14
...percent cut [2]	50.7	749	936	579	.53	.89
...ar-cut		448	274	149	.63	1.95

[1] Shrubby understory had been removed from half of each plot in 1931. On the clear-cut plot, aspen ...s were removed with the shrubs. Where sprouts remained, the pines died out.
[2] Described in terms of crown area removed.

Where sapling- and pole-sized conifers are found as an understory ... aspen, careful examination almost invariably reveals that both ...pen and conifers seeded-in within a few years after a fire. Aspen, ...ng the more rapid grower, soon overtops pine, but may not always ...ppress it completely. A good example of such a stand was selected ...r study in 1931. The pines were 25 to 35 years of age and 18 feet ...gh, and were overtopped by 35-year-old aspen and birch. Trees ... all species were of seedling origin and apparently had become ...tablished after fire in a pine stand. The pines had grown well for ...e first 10 to 20 years, though not so rapidly as these species grow in ...re stands, natural or planted. During the next 10 years, however, height growth averaged less than 6 inches a year and progressively declined. Here reduced growth was due not to suppression by the understory but to destruction of leaders by aspen branches. The average pine tree had had its terminal destroyed three times. After removal of the aspen in 1931, the pines immediately thickened their crowns and resumed rapid growth (table 5). Good stands of pine such as this are well worth saving by removal of the aspen. Additional studies made in Minnesota and Michigan by the writer and others (*2*, *16*) have indicated that an aspen overstory if dense is deleterious to conifers of all ages.

TABLE 5.—*Growth of 25-year-old white pines after cutting in aspen overstory*

Treatment of aspen and date of observation	Pines per acre		Average height of pines		Basal area of pines per acre	
	Count	Difference	Measurement	Difference	Measurement	Difference
	Number	*Percent*	*Feet*	*Percent*	*Square feet*	*Percent*
Uncut:						
1931	226	------	17.6	------	6.85	------
1936	175	−23	20.8	18	7.34	[illegible]
45-percent cut:						
1931	231	------	18.1	------	7.67	------
1936	206	−11	21.8	20	10.56	[illegible]
Clear-cut:						
1931	315	------	21.3	------	14.48	------
1936	259	−18	25.0	17	19.37	[illegible]

If pines or other conifers become well established at the same time as aspen seedlings and escape being overtopped by undergrowth, they often persist as an understory until the aspen matures and is logged or decays normally. It is only in such cases that conifers can naturally succeed aspen at the end of the first aspen cycle. Such mixed stands make up only a small part of the total present extent of aspen forests, but they are commonly cited as demonstrating the natural successional trend. Observations on many such stands throughout the Lake States indicate that where aspen is dense enough to form a stand, pines are present only as seedlings of the same age as the aspen, or as small seedlings that live for a few years and then die.

It is doubtful whether aspen stands favor the development of conifers at any stage. The argument for aspen as a nurse crop for Lake States conifers is thus seen to be spurious in all cases except where the aspen is thinned artificially or occurs naturally as scattered individuals on dry, sandy soils. Here the shade and protection it affords from drying winds is of definite benefit to conifer seedlings, as will be brought out more fully in a later section.

The studies reported above, together with many others not mentioned in detail, supply the factual basis for a definite answer to the question. What happens to conifer seeds and seedlings in aspen forests?

After a good seed year thousands of conifer seed fall to the ground beneath the parent tree. Most of these are eaten by birds or mice. Of the few escaping, only those that happen to fall on exposed mineral soil or on rotten logs can germinate. During the first summer, heavy mortality occurs as the result of intense shade, or drying-out of the surface soil, or damping-off caused by fungi. Seedlings surviv-

[illegible] the first summer are buried under a mat of aspen leaves during [illegible] first winter. Again, only the most favorably located seedlings [illegible]vive. The shade and root competition of overstory and under[illegible]wth prevent seedlings from increasing in height more than 1 to 3 [illegible]es annually. When the seedlings are about 5 years of age, deer [illegible] hare begin to feed on them. If this does not completely destroy [illegible]m, it at least prolongs the period during which they are likely to [illegible] destroyed, and prevents them from making sufficiently rapid growth [illegible] overtop the tall herbs and shrubs surrounding them. One by one, [illegible] weakened seedlings succumb as a result of browsing, insect attack, [illegible]tting by leaves, shading, or other causes. Few persist for as long [illegible] 10 years.

MEASURES FOR RESTORING CONIFERS

All the factors described above—poor natural seeding, unfavorable [illegible]dbeds, plant competition for light, moisture, and soil nutrients, and [illegible]mal hazards—must be taken into consideration in formulating eco[illegible]mical and expeditious methods for converting aspen forests to coni[illegible]. The procedure described here is based upon the experiments dis[illegible]ssed and upon a wealth of additional experience accumulated over [illegible] period of 10 years on more than 90 different experimental plots and [illegible]ntations scattered throughout the Lake States.

SELECTION OF PLANTING SITES

There can be no question as to the desirability of restoring conifers [illegible] soils upon which aspen fails to reach pulpwood size before becom[illegible]g decadent. It is on such land that aspen and undergrowth are [illegible]t aggressive and consequently are most readily displaced. Aspen [illegible] poor soil may be replaced with conifers by planting at any age, [illegible] the operation will be less expensive if carried out before the stand [illegible]ains a height of 15 feet. But soils too poor for aspen usually are [illegible]r for conifers also, whereas the soils on which aspen is most [illegible]gressive are those capable of supporting the best stands of pine [illegible] spruce. Restoration of conifers, an expensive undertaking even [illegible]der the most favorable conditions, is more readily justified on lands [illegible]om which the greatest returns can be expected. In practice, selec[illegible] of lands is usually not difficult. Areas of good soils are first [illegible]oice provided the aspen is less than 12 feet high and is not dense. If aspen on good soils is dense and 15 feet or more in height, it will [illegible] expensive to convert.

Areas severely burned and supporting only scattered aspen seed[illegible]gs can usually be cheaply prepared for planting by plowing fur[illegible]ws and should be given high preference. Conifers can be intro[illegible]ced successfully, also, after logging of mature aspen. The finan[illegible]al returns from the logging operation will go a long way toward [illegible]fraying the costs of preparing the soil and planting. Logging is [illegible]llowed by less sprouting if done in summer. To date little experi[illegible]ce has been gained in restoring conifers on swamplands, and large-[illegible]ale work on such lands should be deferred until results have been [illegible]tained on experimental areas.

Few planting sites in the Lake States are uniform over any large [illegible]ea. Swamps, clay ridges, stream courses, and rocky areas where planting of conifers is impracticable, together with areas of good aspen or hardwoods, break up the planting site in such a way that a good mixture of species normally will result without the necessity of special precautions. Where large, uniform stands of low-quality aspen do occur, scattered strips should be left as firebreaks and to furnish insurance against the ills to which large areas of pure conifers are subject.

It seems desirable to concentrate conversion work chiefly on areas where the site can be prepared by mechanical methods, such as are described later.

Selection of Species

Of the conifers native to the Lake States, jack pine makes by far the most rapid growth in early life and for this reason requires fewest weedings. It is particularly well adapted for use on areas of sandy soils supporting decadent aspen or brush. Red pine, white pine, and white spruce are as a rule more expensive to establish, but the greater returns to be expected from them will often justify their use on the better soils. Because of danger from blister rust, white pine should not be used where currants or gooseberries are too abundant to be removed at reasonable cost. White spruce is especially to be recommended where soil conditions are favorable, because it is readily marketed in small sizes for pulpwood and it withstands competition better than any other native conifer except balsam fir. Fir, because of its slow growth, early decadence, and low value, is not recommended for general use. Black spruce (*Picea mariana*), red spruce (*P. rubra*), Norway spruce (*P. excelsa*), tamarack (*Larix laricina*), European larch (*Larix decidua*), and eastern hemlock have been tried, but all have proved disappointing. Only hemlock merits further trial on uplands. For swampy areas black spruce, tamarack, and northern white-cedar (*Thuja occidentalis*) are the only suitable species.

Selection of Planting Stock

Since the crucial element in replacing aspen is getting the conifers above the undergrowth, anything that hastens early growth increases the probability of success and tends to reduce cost; conversely, anything that delays early growth increases the probability of failure and adds to cost. Attempts to cut costs by direct seeding or by using small-sized or poor-quality planting stock have either failed completely or led to greatly increased costs because inferior stock requires a longer period of care.

The advantages of using large transplant stock are clearly brought out by the results from a 19-acre test planting made in 1933. The site had been logged for hardwoods and aspen saw timber in 1929 and had been gone over by fuel-wood cutters in 1932, so that only a few trees remained in the overstory. All sprouts and shrubs were cut with scythes to prepare the area for planting. Acre plots were laid out, and on each plot were planted 2,250 trees of a single species and age class. Survival was high on all plots for the first 2 years, but during the third growing season, 1936, a period of severely hot, dry weather caused heavy losses (table 6). The older age classes survived this far better than the younger. The most

[illegible] 6.—*Influence of age class on survival and height growth of conifers planted in the fall of 1933 on acre plots of aspen land*

Species and age class	Survival: Fall of 1935	Survival: Fall of 1936[1]	Height in fall of 1936
	Percent	*Percent*	*Feet*
[illegible] pine:			
[illegible]	97	73	1.8
[illegible]	98	46	1.1
[illegible]:			
[illegible]	89	53	1.4
[illegible]	75	51	1.3
[illegible] spruce:			
[illegible]	98	81	1.9
[illegible]	95	47	1.1

[1] [illegible] summer of 1936 was extremely hot and dry in this region.

[...]rkable showing was made by 2–2[12] stock of white spruce, a [...]cies usually susceptible to drought. This is all the more note[...]thy because the stock was so large at the time of lifting that [...]as thought unsuitable for field use.

The advantages of large stock are illustrated further by the results [...]m a 36-acre test planting made in 1934, in which more aspen trees [...]e left in the overstory than in the 19-acre experiment. Although [...] planted conifers had 1 year less in the field, and the soil was less [...]tive of moisture, there was better survival during the severe [...]mer of 1936 than in the other plantation. For the planting of

[illegible] 7.—*Influence of grade of stock on survival and height growth of conifers planted in the fall of 1934 on acre plots of aspen land*

Type of plot, species, and age class	Grade	Survival: Fall of 1935	Survival: Fall of 1936[1]	Height in fall of 1936
		Percent	*Percent*	*Feet*
[...]ped spots:				
White pine:				
2-0	Small	91	61	0.50
2-0	Large	93	81	.67
Red pine:				
3-0	Small	96	71	.50
3-0	Large	92	72	.56
White spruce:				
3-0	Small	95	48	.70
3-0	Large	99	81	.95
Jack pine:				
2-0	Small	97	93	1.53
2-0	Large	97	96	2.43
1-0[2]	do	98	93	1.50
[...]ed furrows:				
White pine:				
2-0	do	96	80	.47
Red pine:				
2-0	do	95	76	.52
White spruce:				
2-0	Small	96	78	.60
2-0	Large	97	86	.85
Jack pine:				
2-0	Small	95	89	1.27
2-0	Large	97	91	1.73
1-0[2]	do	96	83	1.01

[1] The summer of 1936 was extremely hot and dry for this region.
[2] Stock from experimental nursery. This is not comparable with other jack pine stock.

[12] In symbols classifying nursery planting stock, such as 2–2, the first numeral indicates the number of years in the seedbed, the second numeral the number of years in the transplant bed. Thus a 2–2 or a 3–1 tree, for example, is 4 years old from seed.

TABLE 8.—*Species and age classes of stock recommended for planting on aspen and brush lands*

Species	Age class	Minimum top length
		Inches
Jack pine	1-1	[illegible]
Red pine	1-2, 2-1, 2-2	[illegible]
White pine	2-2	[illegible]
White spruce	2-2, 2-3	[illegible]

this acreage the nursery stock was first carefully graded as large and small. As in the other experiment, 1 acre was devoted to each species and size class. The larger stock gave appreciably better survival for all species except red pine (table 7). Compared with the other species, jack pine survived the drought with remarkably few losses.

From these experimental results it is apparent that only high-grade stock having sturdy stems and well-balanced root systems should be used. The stock should fulfill other requirements of high-grade planting stock, i. e., should be of thrifty appearance and good color, be well hardened against both cold and drought, and have a good reserve food supply. Succulent stock that has been produced in richly fertilized or heavily watered beds should be avoided, as well as weak stock produced on poor soils inadequately watered and fertilized. Minimum specifications as set forth in table 8 call for 2-year-old jack pine, 3- to 4-year-old red pine, 4-year-old white pine, and 4- to 5-year-old white spruce.

FIGURE 7.—Jack pine planted in the fall of 1934 and weeded in 1935, 1936, and 1937, as it appeared in 1938, after the remaining aspen trees had been girdled.

[illegible]ING COMPETITION FROM OVERSTORY, UNDERGROWTH, AND ROOTS

The overstory should be thinned so that at least 50-percent light [illegible] the planted conifers. This usually involves removing more [illegible] half the trees if the stand is fully stocked. Best results are [illegible]ed by leaving just sufficient overstory to provide shade for each [illegible]ed conifer during some portion of the day. Figure 7 shows [illegible] overstory left in the 36-acre experimental planting, which came [illegible]gh the drought of 1936 with remarkably small losses (table 7). If the overstory is dense, failure to thin it, even though the under[illegible] is removed, will result in poor growth of the conifers, as was [illegible]ated by the data on uncut plots presented in table 2. These [illegible] were weeded far more intensively than would be practical in [illegible]-scale work. On two 1-acre aspen plots planted with 3–0 white [illegible] in the fall of 1931, the undergrowth was kept down by periodic [illegible] but the overstory remained intact. Five years after plant-

[illegible] 8.—Stand of 53-year-old aspen 5 years after underplanting with 3–0 [illegible] spruce. Only about half the spruce trees are visible above the snow, [illegible] averaged about 8 inches in depth. The undergrowth had been removed [illegible]ly, the overstory left intact.

ing, survival of the planted spruce trees averaged 79 percent, but their height averaged only 1.1 feet (fig. 8). This represents an annual height increment of barely 0.1 foot. Replacement of aspen with conifers is obviously not practical unless the latter grow more rapidly than this.

Undergrowth in the planting rows must be either thinned or completely cut out. Failure to do this is in many cases more serious than leaving the overstory intact, as pointed out on p. 17. From a wealth of additional evidence that thinning the overstory alone is insufficient, one experiment will be cited. White pine and white spruce were planted, in 1930, on six aspen plots thinned to varying degrees. When examined 6 years later, only 38 percent of the white spruce and 15 percent of the white pine remained alive, and the trees of the two species, respectively, were but 3 and 2 inches taller than when planted (table 9). Though hares had fed on these plants from time to time, the chief cause of slow growth and low survival was competition of the undergrowth. Undergrowth has been found similarly to restrict the development of natural reproduction of red spruce in the southern Appalachians (*8*) and of red and white spruce in New England (*15*).

The most practical method of keeping down the undergrowth is periodic mowing.

TABLE 9.—*Survival and height of white pine and white spruce on six plots 6 years after planting in a thinned 20-year-old aspen stand* [1]

Plot No.	Aspen trees per acre after thinning	Average diameter at 4½ feet	Light intensity at 4 feet	Survival		Height [2]	
				White pine	White spruce	White pine	White spruce
	Number	*Inches*	*Percent*	*Percent*	*Percent*	*Inches*	*Inches*
1	[3] 920	3.2	20	8	42	3.6	[illegible]
2	400	3.8	18	9	26	3.1	[illegible]
3	398	3.5	12	17	33	3.5	[illegible]
4	196	4.4	25	22	41	4.4	[illegible]
5	196	5.3	34	24	52	4.1	[illegible]
6	112	4.6	28	11	31	4.7	[illegible]
Average				15	38	3.9	[illegible]

[1] The planted trees were not released from competition of undervegetation.
[2] Average heights at time of planting were: White pine 2 inches, white spruce 3 inches.
[3] This plot was not thinned.

A long record of both experimental and routine plantings in the Lake States has conclusively demonstrated the impossibility of success without soil preparation that eliminates tops and roots of competing vegetation from the neighborhood of seedlings during their first growing season. Spots 20 to 24 inches square may be freed of roots of competing vegetation by scalping, but this method is expensive and the spots may have to be hoed out during the first or second growing season if grass or other herbaceous vegetation present on the area is aggressive. Furrowing is usually cheaper and eliminates competition more effectively. Furrows should be 3 to 6 inches deep and should have flat bottoms 14 inches wide. Those prepared with plows having right and left shares and moldboards

...ate vegetation ...rip about 3 feet (fig. 9). Furrows of such width ...ferred. Plowing ...st be done long ...h in advance of ...g to allow the ...s to settle thoroughly.

...ting furrows ...be prepared ...before or after ...ing. The presence of large stumps ...ged areas makes ...ing more expensive than on areas ...pied by young ... stands. An ...plowed after logging is shown in figure 10.

FIGURE 9.—Planting conifers in prepared furrows, 3 to 6 inches deep and 14 inches wide at the bottom, is a cheap and effective means of eliminating root competition. Here low-quality aspen forest is being converted to conifer in this manner. The trees are 2–1 red pine, 1 year in the field. No weeding was necessary the first year after the furrow was plowed.

...TING METHOD AND SPACING

...pains should be ...d to make sure ...the trees are ...erly set in the ... Since only large... stock is recommended for use, the trees should be planted by a deep-hole method ...posed to a slit method. Spreading the roots over a mound or ...e of soil built in the center of the hole has been found to result ...tter survival and to reduce frost heaving. This "inverted-V" ...od is therefore recommended for use in plantings on aspen and ...h lands. On heavy soils subject to heaving, planting should be ... in spring; on sandy soils, it may be done either in spring or ... fall.

Close spacing is recommended, since it shortens the interval before ... crowns close and consequently the time during which the planted ... must be protected from competing vegetation. A spacing of ... by 6 feet is possible if the soil has been scalped. In tall brush ... aspen, close spacing of furrows is usually unpractical because of ... crossing of felled stems. Here close planting within the furrows ... recommended.

PROTECTING YOUNG PLANTATIONS

Complete elimination of fires from young conifer plantations is ...ntly necessary. Protection from deer, snowshoe hares, and rab-

FIGURE 10.—Aspen area plowed in furrows after logging and brush clearing, then planted to conifers. Two-year red pine seedlings are growing in the furrows shown.

bits is almost equally important. To some extent the degree of protection required can be diminished by selecting sites near villages or in other places where these animals are scarce, and by avoiding the neighborhood of swamps that serve as winter yarding grounds. Plantings that are established in years when snowshoe hares are obviously going through the low portion of their population cycle are likely to require little protection.

Since the snowshoe hare has a narrow cruising radius, once these animals are cleaned out of an area they are slow to return. Driving, organized shooting, and snaring may all be used successfully to protect large planting areas. Snaring, if skillfully done, is probably the cheapest method of eliminating hares. Wire nooses may be set in natural runways or in passageways left in long barriers constructed of brush or slashings. In using the latter method, better results are obtained if the snares are left unset until the animals become accustomed to using the passages.

Experimental plantings and others requiring the most effective protection possible should be fenced. Poultry netting 5 feet wide erected with posts set 10 feet apart makes a very satisfactory fence. The lower edge of the netting should be placed in a trench 4 inches deep, and turned outward to discourage burrowing. One-inch netting, which will turn young hares, is recommended for the lower 2 feet, and 2-inch netting of 24- or 36-inch width for the upper part. A single strand of 8-gage smooth wire strung 6 inches above the netting and fastened to it by 20-gage smooth wire adds greatly to

strength and permanence of the fence. Such a fence, erected, costs between $400 and $500 per mile. Each spring and fall it must be repaired where it has been broken by windfalls or undermined by woodchucks. Deer may occasionally break through it, especially during the first few weeks after erection. If this happens the animals should be chased out and the fence promptly repaired, before they become accustomed to feeding in the plantation. Rabbits enclosed at the time of fencing or entering later through holes may be snared or shot.

The likelihood that such drastic measures will result in undesirable reduction of game and other wildlife is remote, for plenty of unfenced feeding grounds will remain.

WEEDING

No hard and fast rules can be set for the time to start weedings or cleanings or for the requisite frequency or total number of such operations. Best results are obtained if competing vegetation is kept at a minimum at all times. It is particularly important that the plants be kept free from suppression during the first years, in order that they may pass quickly through the juvenile stage in which they are likely to be destroyed by rabbits, deer, or competing vegetation. There appears to be no merit whatsoever in allowing the planted conifers to remain suppressed for periods of 2 to 4 years before beginning to weed. This merely prolongs unnecessarily the length of time during which protection and care are required, and all too frequently results in complete loss of the planted trees. Furthermore, any individual or agency that continues planting for 4 years before beginning to weed builds up a future obligation that will be difficult to meet. If weeding is recognized as a necessary part of the current program, there is more likelihood that the plantation project will be carried through successfully.

Weeding should be repeated each year until the trees are free from overtopping vegetation. This may mean 2, 3, or 4 years, or even longer. The number of weedings required may be reduced by judicious selection of a time for doing the work. The best time of year to cut shrubs and hardwood sprouts is after the annual height growth culminates, but before the new leaves have had an opportunity to restore the reserve food used up in forming them. In the Lake States region, this stage usually occurs between June 15 and July 15. Three annual weedings at this time of year will in most cases reduce the vigor of the underbrush to such an extent that it will require little attention thereafter. Cleanings at this time also give the planted conifers an opportunity to build up a reserve of food and to become hardened against late summer drought. Weedings delayed until late August or September may just as well be postponed until the following spring, since exposure of suppressed plants late in the season often results in losses due to drought or to winter injury.

The brush scythe and machete have proved to be the most useful tools for weeding plantations. Which tool should be used depends upon the character of the brush to be cut and the skill of the crew. Machetes are usually better on deeply furrowed areas, and scythes on areas that have been scalped or shallowly furrowed.

In protecting the conifers from being overtopped by shrubs, care must be exercised not to promote development of a dense sod of grass, sedge, and low herbs, which might harbor larvae of the May beetle (*Phyllophaga* sp.) and would make a heavy drain on the soil moisture; in other words, not to change the forest environment into a field environment. Hardwood leaves are about the cheapest and most effective deterrent to grasses. Where sod is aggressive, only brush that is restricting the growth of the planted trees should be cut. If grass invades scalped spots during the first or second season to such an extent that growth of the trees is reduced drastically, the sod should be removed by hoeing around each tree. A heavy I-type hoe with a narrow blade, such as the sprouting hoe, is most satisfactory for this purpose. This hoe is fitted with a 4½-foot handle.

Areas prepared for planting by use of heavy machinery are not likely to require weeding the first year. Thereafter weeding should be done along the furrows and extended far enough on either side to prevent serious overtopping. The brush on the intervening strips may never need to be cut. After the conifers form a closed canopy the brush will gradually disappear.

Removing the Overstory

Normally the overstory should be removed when the planted conifers have reached heights of 4 to 6 feet. It is desirable, however, that only relatively narrow strips of plantation be exposed at one time, until the conifers have formed a closed canopy. In large plantations, scattered clumps of aspen should be left to prevent drying winds from gaining free access to the soil. If the overstory trees have no commercial value they may be killed by girdling, which results in less sprouting from the roots than if the trees were cut, and which by taking effect gradually over a period of one or two years provides a more gradual increase in light. (See fig. 7.) A still longer period during which the girdled aspens lose their branches before falling prevents any excessive physical damage to the young conifers. On areas furrowed at intervals of 10 or more feet, the overstory may be allowed to remain a few years longer, provided it is not interfering seriously with the growth of the planted trees. Spots in the plantation that for one reason or another have failed may be allowed to remain in aspen or to grow up to hardwoods or other species to avoid extensive areas of pure conifers.

Officers responsible for conversion work must learn to recognize the signs of suppression as they arise and to apply promptly the measures to alleviate this condition. Instructions and regulations, however clearly elucidated, cannot be substituted for constant vigilance and sound judgment on the part of the men on the ground responsible for the care of plantations.

Use of Heavy Machinery

It should be perfectly obvious to anyone who has watched the operation of heavy machinery in road building or logging that engineering and mechanics in America are sufficiently advanced to provide machines adapted for preparing aspen or brush fields for

That such equipment is slow in making its appearance indicates that machine designers have not focused their attention on the problem. The task involved is to clear away the underbrush and prepare scalped spots or furrows, as described on page 25, in which trees may be planted. The best equipment tried so far has been the Olympic plow followed by a heavy furrowing plow.

The Olympic plow (fig. 11, *A*) is a modified bulldozer having a V-shaped share built of welded grader blades with a shoe on either side to prevent undue digging. The bulldozer frame with this plow is mounted on a 35-horsepower armored tractor. This plow

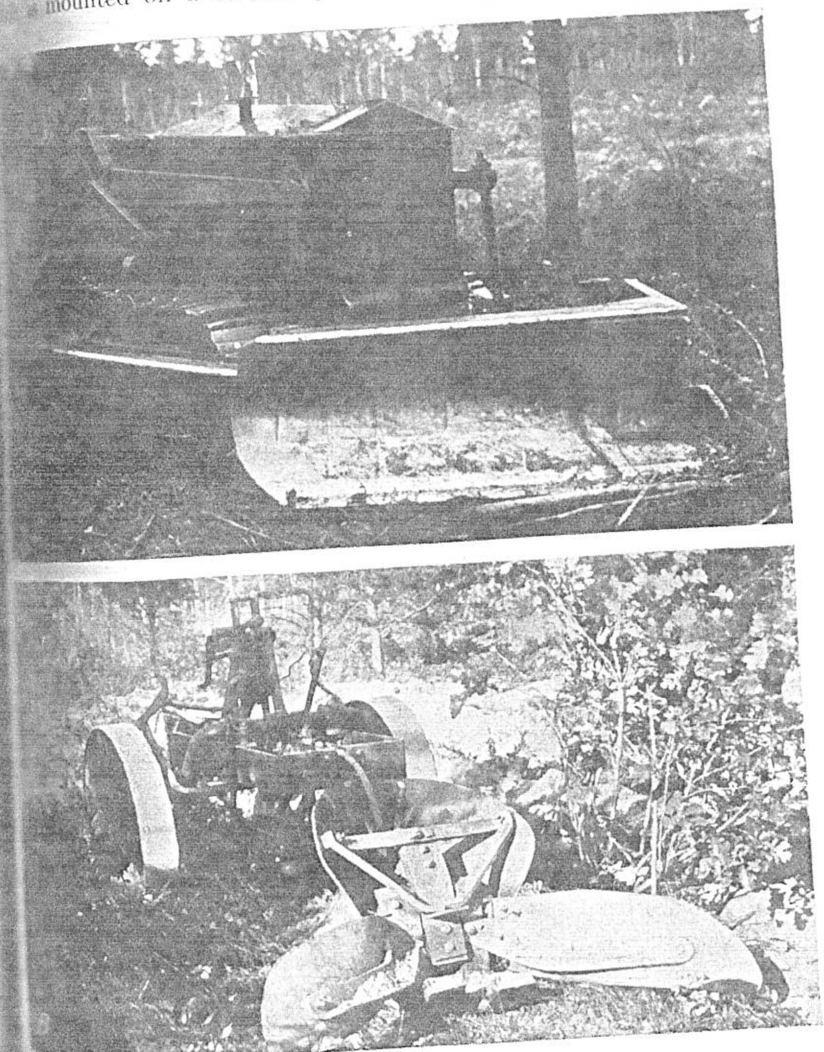


FIGURE 11.—Machinery employed to clear a 5-foot strip through young aspen and brush, in which furrows are prepared for the planting of young conifers: *A*, Olympic plow adapted for clearing; *B*, ordinary planting plow used to make furrow.

FIGURE 12.—Disk-type plow used in heavy brush or poor-quality aspen, alone or in conjunction with the Olympic plow.

...h and small aspen trees from a strip about 5 feet wide. ...tory furrow may then be made with a heavy planting ... 11, *B*), which throws soil up on both sides of the furrow, ...ring a strip about 3 feet wide entirely free of competing ...

...k-type plow (fig. 12) is equally effective when used behind ...pic plow in soils free of stone. This plow does not become ...with brush and other debris, and therefore is simpler and ... operate. It exposes mineral soil in strips 5 feet wide and ...lmost anywhere that the tractor can be driven. If the aspen ... is only moderately dense and its stems are less than 2 inches ...ter this plow used alone prepares satisfactory furrows. ... three types of plow become more widely used in conversion ...any improvements will doubtless be made. Up to 1939, ...n 1,200 acres on the Chippewa National Forest had been ... and furrowed with these implements and planted, fully ...rating the feasibility of using such equipment. It is ex- ... that this equipment will be required more and more as the ...plantable sites become exhausted.

... use of such heavy equipment makes it possible to thin the ...y, remove the undergrowth, and prepare the soil in a dual ... a single operation. This method is recommended wherever ...able.

...ROBABLE COST AND RETURNS OF RESTORING CONIFERS

...y effort to restore conifers on aspen lands in the Lake States, ...n should first be directed toward freeing from complete sup- ...n the conifers that are already well established, provided they ...resent in sufficient density to develop into valuable stands. ...ny cases logging of mature aspen is all that is required to ... the conifer understory. Such stands will be among the first ... logged for aspen in any wisely planned land-management ...m, for in this case conversion to conifers can be effected with ...tlay of funds. Where aspen too defective to be merchantable ...usly retarding or actually killing well-established conifers in ...derstory, the overtopping trees should be cut or girdled. This ...st $2 to $6 per acre, depending on stand density. If, however, ...rs are present only as scattered seedlings less than 2 feet high ...re rarely worth the expense of the continuous care necessary to ... them through the competing undergrowth and overstory ... others are planted to complete stocking.

... is still early to make reliable estimates of the cost of artificially ...ring conifers on aspen lands, since none of the large-scale plant- ... can be considered to be fully established. The experimental ...tings, for various reasons more expensive than large-scale oper- ... would be, have cost from $30 to $100 per acre. Cost estimates ... large-scale conversion projects are as follows:

...ation of site with heavy equipment (based on costs involved in pre-...ing 800 acres with Olympic plow and furrowing plow)	$5
... control (snaring and shooting)	2
... stock	6
...ing	4

Weedings:
- First
- Second
- Third
- Fourth (seldom needed)

Removal of overstory by girdling

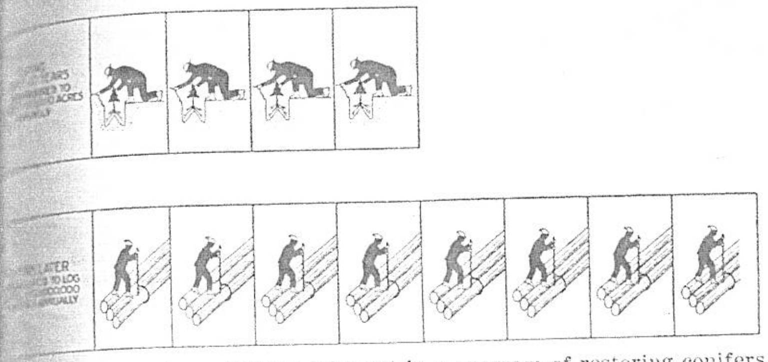
Total

These estimates are based on a site of more than average difficulty and upon use of only moderately experienced workmen paid standard wage rates for woods work. Probably many items of cost can be reduced as more experience is gained in carrying out the essential operations. Areas on which the aspen and the undervegetation are less aggressive should be somewhat less expensive to convert. However, it seems doubtful that any large area of aspen land can be converted to conifer at a cost much below $25 per acre.

No allowance is made in these estimates for returns from sale of merchantable aspen before the land is prepared for conifers, it being assumed that efforts to restore more valuable types will be concentrated chiefly on lands where the aspen is unmerchantable or of low quality. Returns from mature aspen favorably located may offset to a considerable degree the costs of conversion, but inasmuch as stumps of mature trees present an added hazard to machinery the actual saving is likely to be insignificant.

Well-stocked natural stands of jack pine and of mixed red and jack pine growing on average sites of the Chippewa National Forest (on soils too poor to support aggressive stands of aspen) begin to produce merchantable pulpwood and mine timbers at 40 years of age; at 65 years of age they contain 10,000 to 14,000 board feet per acre, worth today from $3.50 to $6.00 per M, depending upon quality, accessibility, and species. It is reasonable to assume that, with the intensive care recommended for conversion planting and with the better quality of aspen soil, comparable growth could be obtained. Such stands logged at the age of 65 years would produce a revenue of $35 to $84 per acre. This would more than offset the costs of restoring conifers, irrespective of such additional revenue as might be obtained by making judicious thinnings at ages of 40 and 50 years. Existing cutting experiments on the Chippewa National Forest indicate that even greater financial returns can be realized and the expense of replanting indefinitely deferred if, instead of clear-cutting at age 65, selective cutting is introduced at age 50 and repeated at 10- to 15-year intervals until the stand has attained an age of 80 years if jack pine or 120 years or more if red pine, white pine, or white spruce. Growth from the fiftieth to the one hundred and twentieth year has been found to average 250 board feet or more per acre annually; hence the total yield up to 120 years would equal approximately 24,000 to 28,000 board feet, worth $84 to $168.

It is clear, therefore, that the labor and other expense required to restore conifers on aspen lands will be met by the returns in the form of timber growth to be expected during the first rotation. This may or may not be adequate to cover interest charges. Even if not, in view of the social and economic benefits to be derived from productive lands, contrasted with the economic drain caused by idle lands, the cost may be well justified. The cost of replacement is, after all,



—Employment possibilities inherent in a program of restoring conifers aspen land. Each symbol represents 1 million man-days annually.

ly a cost of forestry; rather it represents a loss caused by destruction. The total capital loss which destructive logging have caused the Lake States region can never be accurately in fact, until the cost of restoring these lands to useful forests determined.

ation of 10 million acres of aspen and brush land to conifers require approximately 80 million man-days of labor; therefore project represents a tremendous reservoir of useful work for unemployment-relief programs. Timber production approxi- 250 board feet per acre annually might be expected from the to the one hundred and twentieth year after planting. To and mill the total annual yield when all 10 million acres be- productive would require approximately 7.8 million man-days per year. Some forestry care during the productive period enable the stand to perpetuate itself naturally. Hence a pro- for restoring conifers on aspen land not only offers immediate ment but promises support for a sizable population in genera- to come. Immediate and future employment possibilities from of this land are shown graphically in figure 13.

SUMMARY AND CONCLUSIONS

-quality aspen, scrub forests, and brush occupy roughly 10 acres of forest land in Minnesota, Wisconsin, and Michigan. area gives little promise of producing merchantable forest prod- ther than fuel wood and posts unless the existing cover is replaced e valuable species. It is estimated that had this land become ked with the original types it could be yielding annually at least llion board feet of timber instead of its present yield of 75 mil- board feet. The difference is worth $1,500,000 on the stump, and support a $7,500,000 forest industry. Available evidence indi- that aspen is continuing to displace more valuable types in the States, and that areas newly invaded by aspen after logging and far more than offset those naturally reverting each year to coni- Furthermore, logging and fires, which destroy and ultimately ate conifers, tend to rejuvenate and thus to perpetuate aspen.

Natural restoration of conifers to lands now occupied by aspen is slow and uncertain. Throughout the aspen and brushlands, conifer seed trees are too scarce to supply adequate seed, and seedbeds favorable for pines are infrequent. The greatest obstacle of all is the competition of shrubby and herbaceous undergrowth taking needed moisture and reducing light intensity below that required by conifers for survival and satisfactory growth. Such competition may cause conifers to remain for a long time at small sizes, subject to repeated injury by deer, rabbit, and snowshoe hare. Deer, rabbit, and hare, though unlikely to destroy completely any conifers that are thrifty and making rapid growth, frequently finish off those already weakened through suppression by shrubs and herbs. Only in the infrequent instances in which conifers become well established at the same time with aspen seedlings and escape being overtopped by undergrowth can they be expected to gain dominance naturally at the end of the first cycle. Instead of serving as a nurse crop for conifer seedlings, aspen usually smothers and kills them.

Artificial restoration of conifers to aspen lands involves the following measures:

1. Choosing areas, preferably of good soil, on which aspen is small or sparse or areas on which aspen has just been cut, and not in the vicinity of swamps used by deer as winter yarding grounds.
2. Choosing tree species to suit soil quality, as the rapid-growing jack pine and red pine for poor soils, the valuable white pine and white spruce for good soils.
3. Using large, high-quality transplant stock, preferably of the following age classes: Jack pine 1–1; red pine, 1–2, 2–1, or 2–2; white pine, 2–2; white spruce, 2–2 or 2–3.
4. Thinning the aspen overstory so as to admit 50-percent or stronger light but leaving an overstory sufficient to shade each planted conifer during some portion of the day.
5. Opening up the undergrowth to prevent excessive shading and root competition.
6. Preparing the planting area by plowing furrows or by carefully scalping 20-inch-square spots, so that the trees will be free from immediate competition of other vegetation.
7. Planting carefully by the deep-hole method, using the "inverted V" to ensure spreading of roots.
8. Maintaining rapid growth by early and frequent weedings until the conifers have overtopped the undergrowth.
9. Protecting planted trees from deer, rabbits, and hares by fencing or spraying, if necessary.
10. Removing the overstory when the conifers have reached heights of 4 to 6 feet, exposing relatively narrow strips of plantation at one time and leaving enough overstory material to prevent drying winds from gaining free access to the soil.

Judicious use of heavy machinery will facilitate the operations. The Olympic plow, in conjunction with a heavy two-way furrowing plow or with a disk plow, may be used to clear away small overstory trees, open up the undergrowth, and prepare planting furrows; or, where the aspen or brush is only moderately dense and its stems are less than 2 inches in diameter, the disk plow can be used to do all this in a single operation. The brush scythe and machete have proved to be the most useful tools for weeding the plantations.

The cost of restoring conifers to aspen lands will probably amount to about $30 per acre. Possibilities of reducing it much below $20 per acre in any case appear slight. The returns to be expected at the

first rotation of conifers are about $35 to $84 per acre with cutting at age 65, $84 to $168 with selective cutting from the to the one hundred and twentieth year. Although these offset costs, they might not be adequate for interest payments. reason, the work appears to be chiefly a task for public agencies. cost involved and the lack of administrative experience in of work make it impossible to recommend more than a small-program at present. In order that experience may be accumulated small-scale programs should be undertaken on several national State forests in the near future. Restoration of conifers on aspen brushlands may then take rank among useful large-scale conservation projects that could be undertaken in the future for relief of unemployment.

Public Program Needed

In view of the magnitude of the job and the social benefits to be derived from productive land, restoration of conifers in the Lake States must be considered largely a public responsibility.[13] The probable ratio of the returns to the costs alone precludes the possibility of any substantial part of this work being undertaken as a commercial venture.

Prudence would require that no large-scale program of converting aspen or brush land to conifers be launched until greater experience has been gained and more is known of the methods, costs, and success of such undertakings. This is all the more reason why small projects should be started on several national and State forests at once. These must not result in building up obligations for subsequent care larger than the responsible organizations are prepared to assume, lest the entire effort be wasted.

Should a large-scale program eventually be undertaken, the probable benefits to each community involved should be weighed against those obtainable by less expensive conservation measures, which may be of equal or greater local value. Land tributary to good market centers should receive first consideration for planting to conifers. In general, preference should be given to better soils, especially if the aspen is not aggressive and gives little promise of attaining merchantable sizes, and to areas where conifers are already established. Full exploration of the possibilities of such a program should be completed at an early date in order that it may be given proper consideration among other public-works programs of the future.

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[13] Furthermore, only the public can attack the problem at its source, by adopting measures that will restrict further spread of aspen at the expense of the more valuable forest types. Such an attack, to be effective, must embrace a comprehensive research program designed to discover how to ensure natural reproduction of conifers after cutting, education of timber managers in the adoption of methods necessary to obtain natural reproduction, and some degree of public control requiring minimum forestry practices on private timber cuttings.

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